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# RADIOLOGICAL SURVEYS OF PEARL HARBOR, HAWAII, AND ENVIRONS, 1966-1968

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Montgomery, Alabama

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# Radiological Surveys of Pearl Harbor, Hawaii, and Environs, 1966–1968

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From April 1966 through June 1968, the Eastern Environmental Radiation Laboratory of the Environmental Protection Agency (formerly the Southeastern Radiological Health Laboratory, Bureau of Radiological Health, U.S. Public Health Service) conducted radiological surveys of a number of U.S. ports which service nuclear-powered submarines. These surveys were undertaken to determine whether nuclear submarine operations, which include berthing, repair, and servicing, had resulted in radioactivity levels in the harbor which could contribute a detectable radiation exposure to the public.

Six surveys were conducted at five ports with histories of extensive nuclear vessel activities, namely: (1) Thames River, New London, Conn.; (2) Hampton Roads, Va., including Portsmouth, Norfolk, and Newport News, Va.; (3) San Diego Harbor, Calif.; (4) Mare Island Naval Shipyard, Vallejo, Calif.; and (5) Pearl Harbor, Hawaii.

This report describes the conduct of the onsite surveys performed at Pearl Harbor in 1966 and 1968 and presents the results of the laboratory analyses of numerous environmental samples which lead to the conclusions that:

1. Small but detectable quantities of cobalt-60 were found exclusively in the sediment phases of the harbor.
2. Neither the harbor water nor any other environmental samples contained detectable cobalt-60 activity.
3. The total amount of cobalt-60 in the harbor sediment is small compared to the natural radioactivity present in Pearl Harbor and decreased significantly from 1966 to 1968.
4. The levels of cobalt-60 activity in the harbor were well below levels that could contribute a detectable radiation exposure to the public and do not constitute a hazard to public health or the environment.
5. Investigation of the physical and chemical characteristics of cobalt-60 in marine sediments indicates that cobalt-60 and possibly other neutron-activated corrosion products are released in a form which is not biologically available to marine or other forms of life.

Pearl Harbor is the major port for American naval ships in the Pacific Ocean. Included among the United States Pacific Fleet units in Hawaii is the Pacific Fleet Submarine Force which in recent years has consisted of both conventional and nuclear-powered vessels. Due to the nature of nuclear reactors, operations related to naval nuclear-powered submarines constitute a potential source of radioactive discharges to the harbor environment.

In 1966, a radiological survey of Pearl Harbor was conducted which was designed to locate, identify, and quantify the extent of any radioactive contamination of the harbor and its populated environs and to evaluate the public health significance of nuclear waste disposal practices. The 1968 survey was conducted to ascertain what changes in the radiological status of the harbor and environs had occurred in the intervening years.

Both surveys were conducted in essentially the same manner. Initially, a general scan of the harbor was made with an underwater gamma scintillation detector probe at selected points to delineate the areas and relative magnitude of radionuclide deposition. Based on

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these results, the subsequent efforts were primarily devoted to onsite survey and sample collection in the areas of highest activity or population density. This report presents the results and conclusions of the comprehensive environmental studies conducted at Pearl Harbor in these two periods.

*Characteristics of the harbor and vicinity*

Pearl Harbor is located on the southern shore of the island of Oahu, 10 miles northwest of Honolulu. It is comprised of four major lochs: west, middle, east, and southeast (figure 1) with a total surface area of approximately 10 square miles (*1*). Southeast loch, subdivided into Magazine, Quarry, and Merry lochs (figure 2) contains the submarine base, berthing areas, and repair basins.

Fresh water from numerous streams and springs around the harbor perimeter provide inflows of 52.3 million gallons per day to west loch, 26.5 to middle loch, and 57.3 to east loch. There is no gauged flow into southeast loch (*1–2*). Other inflow consists of treated and un-

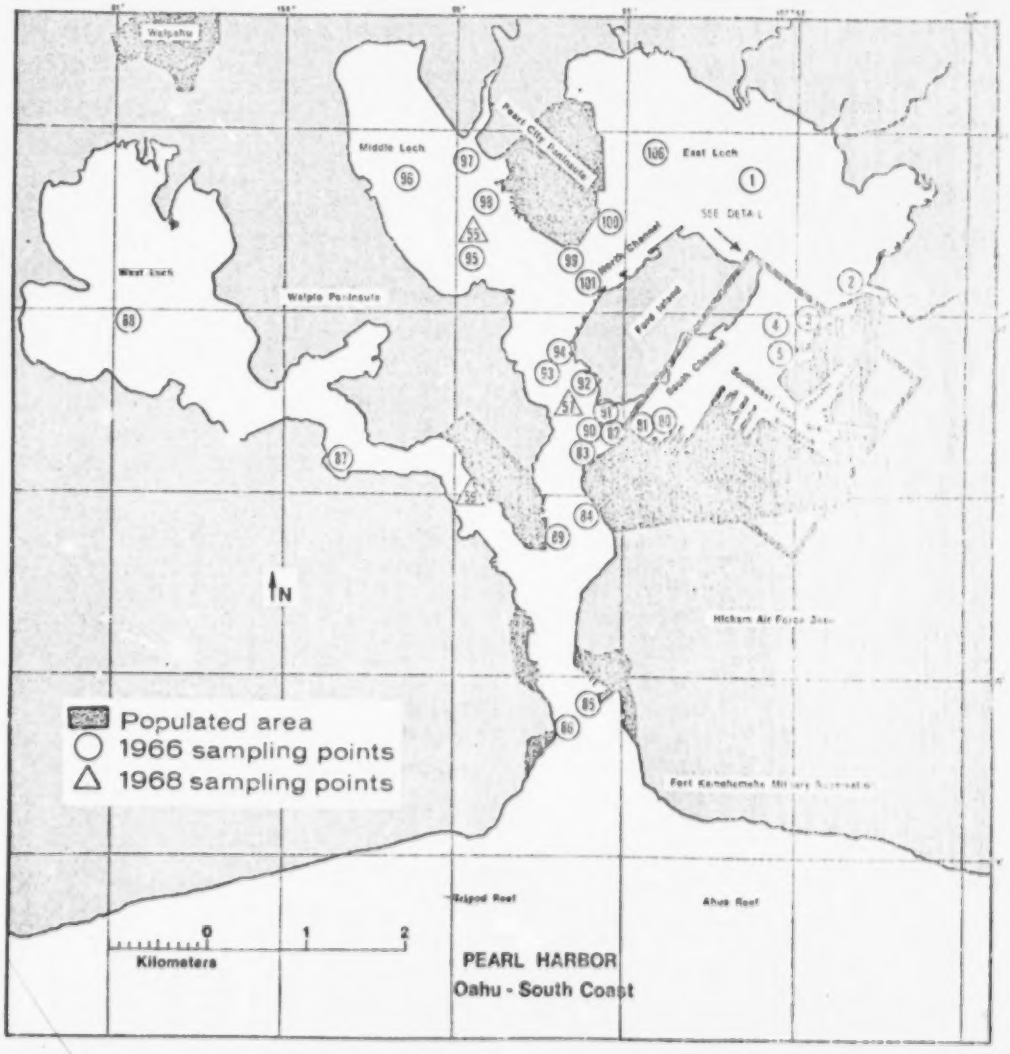


Figure 1. Pearl Harbor sampling locations for 1966 and 1968

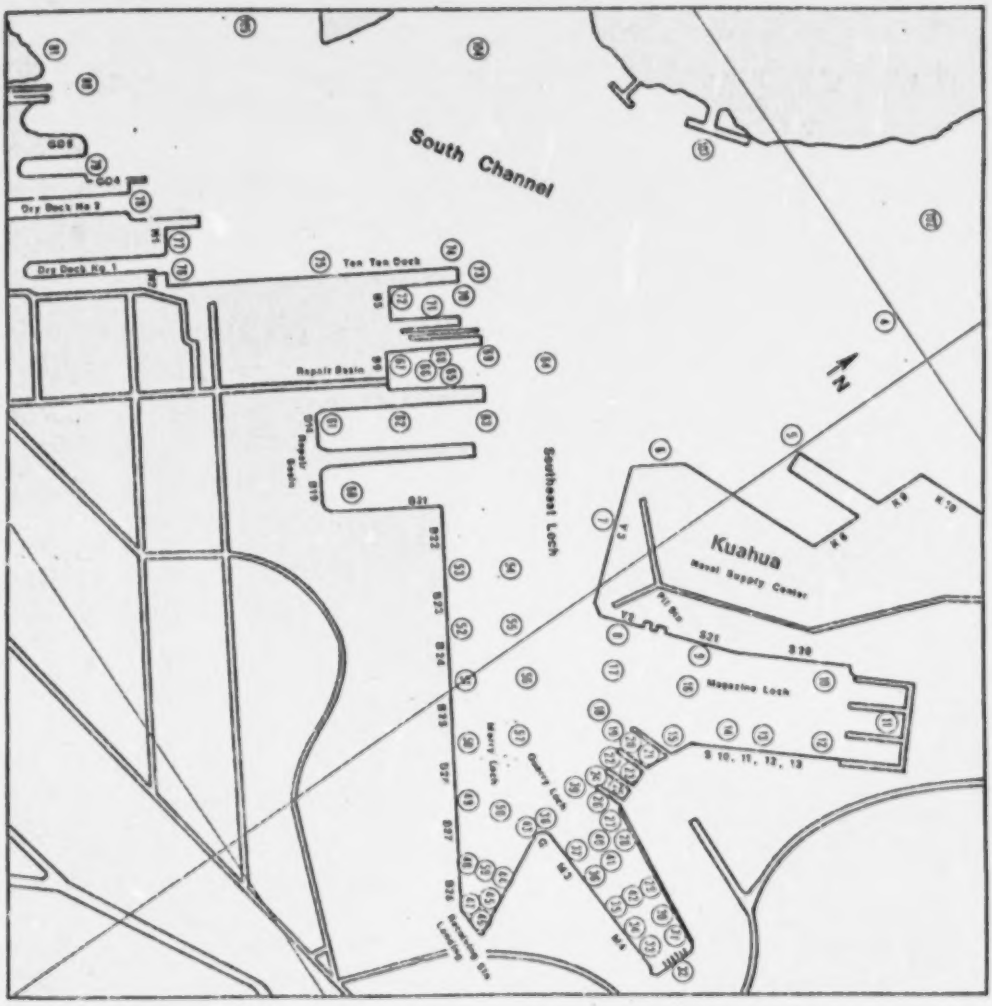


**Figure 2. Pearl Harbor sampling locations for 1966 and 1968 (area of highest concentrations)**

treated sewage waste from both Naval and nearby civilian areas. Because of these waste disposal practices; the harbor waters are polluted and commercial fishing is prohibited. However, oyster beds are present along the harbor shoreline and small fish are caught for bait by salmon fishermen. The average rise and fall of the diurnal tides is approximately 2 feet which is not sufficient to produce noticeable currents within the harbor (*3*).

Pearl Harbor Naval Shipyard had at this time, a population of approximately 4,000. Pearl City, situated on the Pearl City peninsula, which separates middle and east lochs, had a civilian population of 8,200. The city of Waipahu, with a population of 7,600, borders on west loch (*4*). Portions of the areas bordering the harbor are used for sugar cane and watercress production, much of which is consumed locally.

*Equipment*

The field surveys were centered on the use of an underwater gamma scintillation detector system which provided useful onsite data for defining the harbor areas which contained detectable gamma radioactivity. The detection system consisted of an underwater probe connected by electrical cables to a multichannel gamma pulse height analyzer aboard the boat. The spectrometer was powered by a 60 cycle, 115 V a.c., portable gasoline generator. The probe was constructed of a 4- by 4-inch NaI (Tl) crystal and associated photomultiplier and preamplifier sealed within a watertight 7-inch diameter, 0.5-inch thick lucite tube. A fitted styrofoam jacket provided shock and thermal protection for the crystal. This type of probe construction permitted detection of gamma emissions from the harbor water and sediment with a minimum of photon energy degradation.

A modified Landing Craft Mechanized (LCM) with a bow davit for raising and lowering the underwater probe was used for transportation. The flat bottom of the craft provided a stable platform for the electronic equipment and access to shallow areas.

*Sample collection and analyses*

Gamma detector probe readings were obtained by lowering the probe to the harbor bottom and counting for 10 minutes. A gamma spectrum taken from an area of the harbor which had a low level (background) of gamma radioactivity was automatically subtracted. Since no gamma-emitting radionuclides other than cobalt-60 and potassium-40 were detectable in the field, the relative activities of different areas of the harbor were assessed as a function of the counts accumulated in the energy region corresponding to cobalt-60.

Using these data as a guide, bottom sediment and harbor water samples were collected for laboratory analysis from areas of high, intermediate, and low cobalt-60 activities. Bottom sediment collected with a Birge-Ekman dredge was dried at 105°C. in the laboratory, and ground to a fine powder. One-liter aliquots were counted for 50 minutes in a multichannel gamma pulse-height analyzer. Smaller aliquots of bottom sediment were also counted for gross alpha and beta radioactivity. Shore sand was similarly analyzed. Acidified harbor water samples and samples of well, stream, and tap water collected from populated areas surrounding the harbor were counted for 50 minutes in 3.5 liter geometry with the gamma pulse-height analyzer. The residue from evaporation of 1-liter aliquots was counted for gross alpha and beta activities.

Fish, oyster, and watercress samples collected from the harbor and environs by the State of Hawaii Fish and Game Division were preserved in alcohol and shipped to the Eastern Environmental Radiation Laboratory in Montgomery, Ala. Whole samples were gamma analyzed as described. In addition, the fish and oysters were divided into edible and inedible portions for further analysis and finally ashed for gross alpha and beta counting.

In 1968, Navy divers collected 18-inch-long core samples of bottom sediment from selected areas. A 24-inch plastic tube was pushed vertically into the silt until at least 18 inches had been contained. The top was capped, the tube withdrawn, and the bottom capped. On board ship, sweeping compound was added to the tube to retain the natural stratification of the sample. Seventeen of the samples collected were considered to be representative of the area surveyed. In the laboratory, these samples were frozen and cut into 1-inch-thick segments for gamma analysis to provide depth profiles of the radionuclide deposition.

*Results*

Cobalt-60 was present in the harbor in small quantities and could be attributed to nuclear submarine operations. Tripler Army Hospital, the only known isotope user in the vicinity, discharged its isotope waste via an outfall into the ocean, 5 miles southwest of the harbor entrance. Slight, but detectable cerium-144 activities of approximately 1 pCi/g dry weight of sediment were present in the samples collected in 1968. The absence of this nuclide in 1966 and its uniform distribution in low activities throughout the harbor in 1968 suggest that the cerium-144 probably resulted from fallout. Gross beta radioactivities of samples, when adjusted for potassium-40 and cobalt-60 contri-

butions, were <1 pCi/g dry weight. Gross alpha radioactivity was also <1 pCi/g dry weight.

Cobalt-60 was found exclusively in the sediment phase of the harbor. Neither the harbor water nor any other environmental samples contained detectable cobalt-60 activity (table 1). The amount of radioactivity associated with sediments collected from different areas of the harbor corresponded directly to the areas of extensive nuclear vessel operations, i.e., the highest cobalt-60 levels were found in southeast loch, primarily at the berthing area of Quarry loch (figures 3–6). Areas of transient operations such as the main channel and the Naval Ammunition Depot in west loch contained little or no detectable cobalt-60 radioactivity.

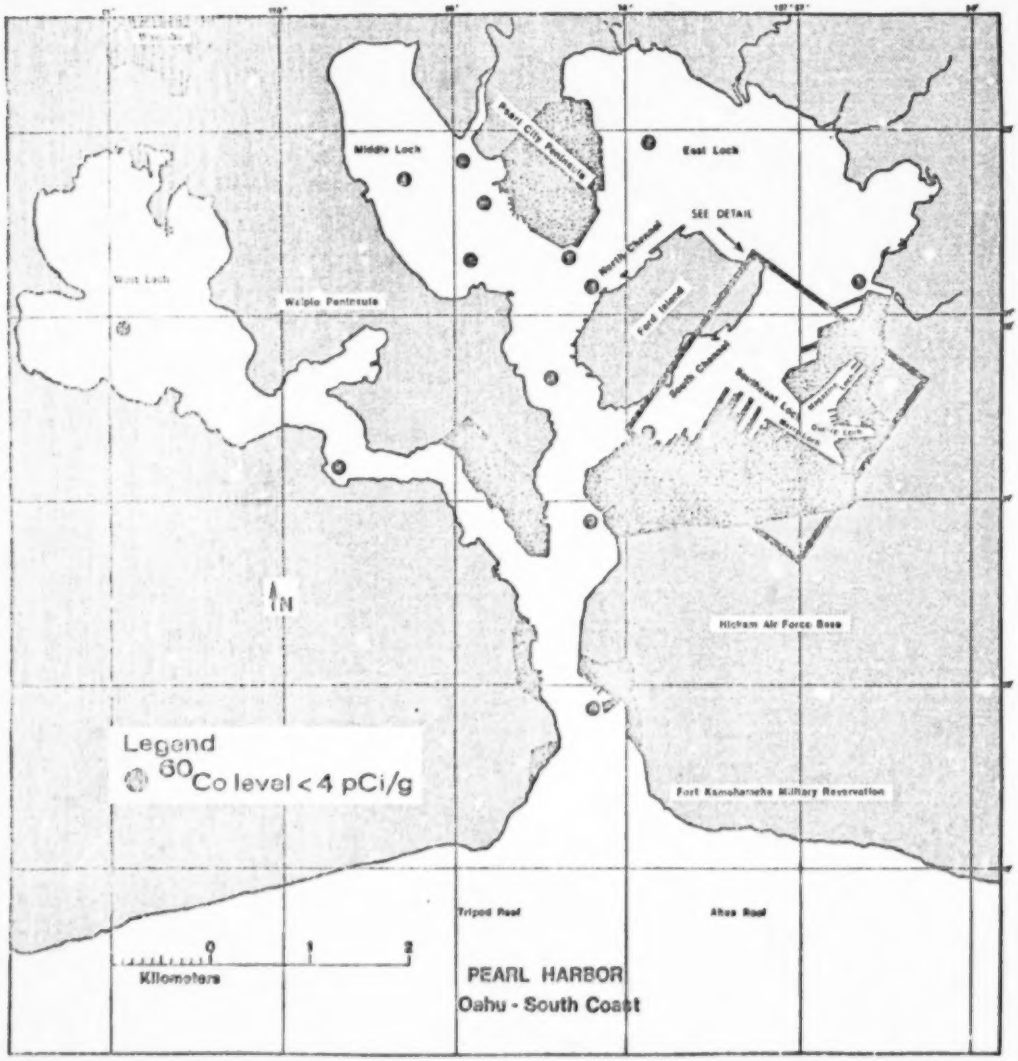


Figure 3. Relative 1966 cobalt-60 levels in Pearl Harbor

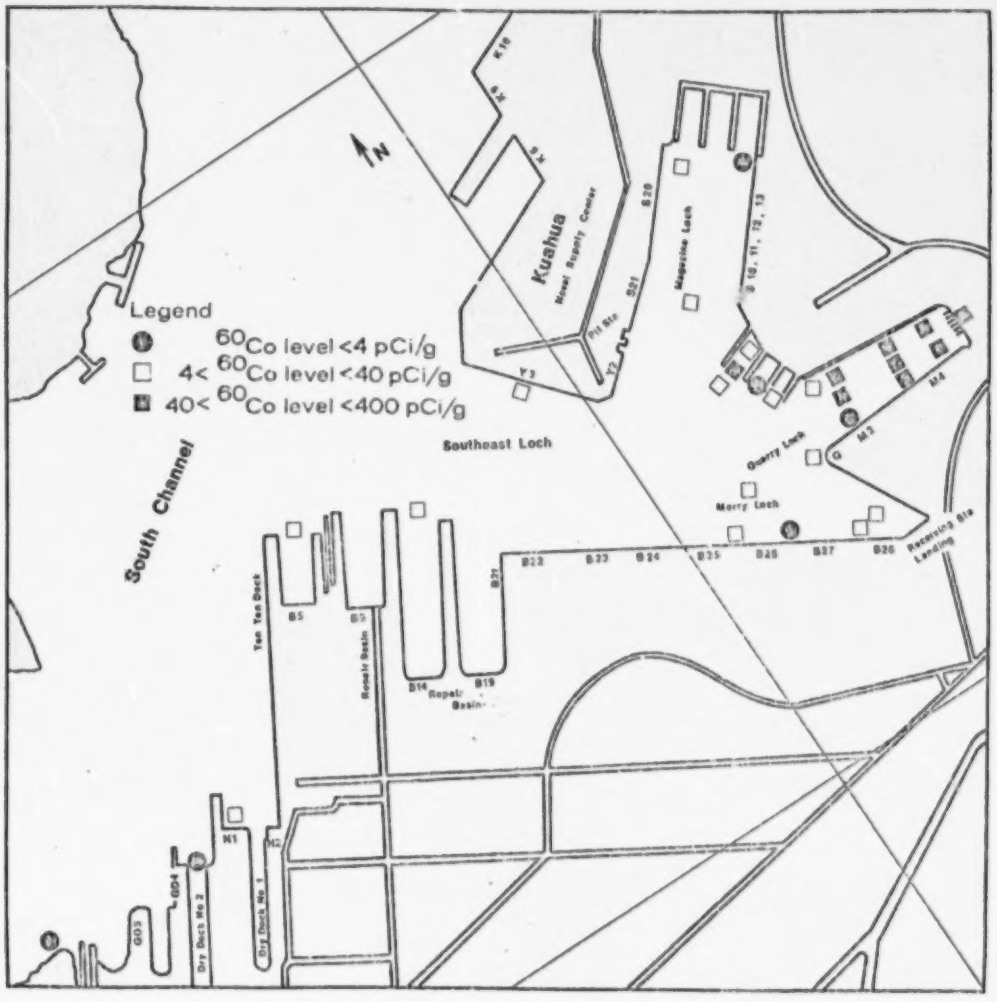


**Figure 4. Relative 1966 cobalt-60 levels in Pearl Harbor (area of highest concentrations)**

**Table 1. Gamma analysis of environmental samples**

| Sample | Location | Gamma activity* |
|---|---|---|
| Tap water: | Pearl City fire station | ND |
| Well water: | Inland of middle loch | ND |
| Stream water: | Sumida farm, Pearl City | ND |
| Shore sand: | Pearl City peninsula | ND |
| Watercress: | Sumida farm, Pearl City | ND |
| Oysters: | West loch | ND |
| Fish: | West loch | ND |
| Harbor water: | Location 11 | ND |
| | Location 21 | ND |
| | Location 29 | ND |
| | Location 32 | ND |
| | Location 33 | ND |
| | Location 68 | ND |
| | Location 78 | ND |
| | Location 81 | ND |

* Exclusive of potassium-40.
ND, nondetectable activity, i.e., <10 pCi/liter of water or 0.04 pCi/g of solids.

The results of the 1966 and 1968 surveys showed that this radioactivity has little tendency to disperse from the probable sites of initial injection into the harbor (figures 3 and 5). Sediment samples comparably collected from the same locations (table 2) showed a statistically significant decrease [2] in cobalt-60 level from 1966 to 1968 (figures 4, 6 and 7).

[2] Mann-Whitney U Test at 0.5 level of significance.

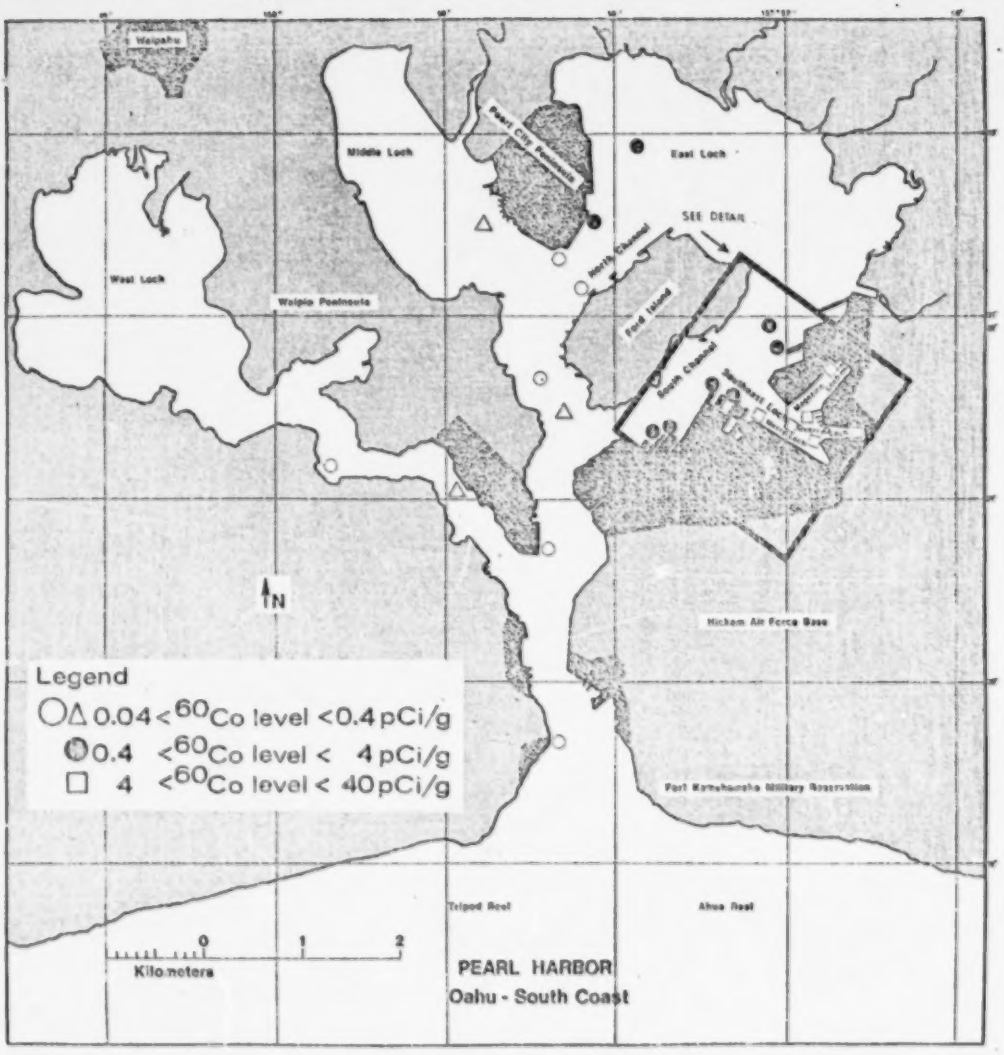


**Figure 5. Relative 1968 cobalt-60 levels in Pearl Harbor (triangles indicate 1968 sampling points only)**

The highest sediment activity detected in 1966 was 105 pCi $^{60}$Co/g versus 33 pCi $^{60}$Co/g in 1968. The average cobalt-60 activity for samples collected in southeast loch was 33 pCi/g in 1966 and 11 pCi/g in 1968. However, core samples collected in 1968 (table 3) suggest that the apparent reduction in sediment cobalt-60 activity may have been in part an artifact of the dredge sampling technique rather than migration of the cobalt out of the harbor. The Birge-Ekman dredge collects appro..imately the top 4 inches of sediment whereas the core samples indicate that the majority of the cobalt-60 activity was at depths greater than 4 inches in 1968. Therefore, the implication is that the decreased cobalt-60 activity is probably due to radioactive decay of cobalt-60 and reduction of direct discharge of nuclear reactor waste into the harbor. In the absence of discharges to the harbor, the contaminated sediment surface of 1966 would have been covered to some extent by uncontami-

**Table 2. Cobalt-60 analysis of harbor sediment obtained by dredge sampling 1966 and 1968**

| Sampling number and location | Cobalt-60 activity[a] (pCi/g dry weight) | |
|---|---|---|
| | 1966 | 1968 |
| 2 Entrance to Halawa stream CINC PAC landing | 0.1 | — |
| 4 Midchannel off USS Arizona | — | 2.2 |
| 5 50 yards off K–8 | — | 2.2 |
| 6 Tied at K–9 | — | 1.9 |
| 7 Tied at Y–9 | 19.2 | 3.8 |
| 10 Tied middle ARD–30 | 4.4 | — |
| 12 Tied at sign S–12, S–13 | 1.5 | 8.3 |
| 16 Midchannel Magazine Loch off S–21 | 14.2 | 9.4 |
| 17 Middle of entrance to Magazine Loch | — | 5.9 |
| 18 100 yards off entrance to S–7, S–8 | 20.7 | — |
| 19 Middle of entrance to S–7, S–8 | 52.8 | — |
| 20 Center of S–7, S–8 | — | 8.4 |
| 21 Tied middle sub-base barge | 34.2 | — |
| 22 Middle entrance to S–5, S–6 | 2.4 | — |
| 23 Middle of base of S–5, S–6 | — | 5.8 |
| 24 Middle entrance to S–3, S–4 | 9.6 | — |
| 25 Tied middle of base of S–3, S–4 | — | 4.9 |
| 27 Tied middle of S1C | 14.2 | — |
| 28 Tied at sign S1B, S1C | 73.4 | 29.2 |
| 29 Tied at sign S1A, S1B | 78.6 | 30.7 |
| 30 Tied 1/4 way down from sign S1A | — | 25.0 |
| 31 Tied at sign S1A | 105.1 | 14.1 |
| 32 Tied middle small boat piers | 104.7 | 13.9 |
| 33 Tied opposite sign S1A | 58.8 | 15.1 |
| 34 Tied opposite location 30 | — | 11.5 |
| 35 Tied opposite sign S1A, S1B | 50.6 | 17.5 |
| 37 Tied opposite middle S1C | 2.1 | 16.3 |
| 38 Tied middle Merry Point pier | 5.2 | 7.9 |
| 40 Midloch off middle of S1C | 62.3 | 19.5 |
| 41 Midloch off sign S1B, S1C | — | 20.9 |
| 42 Midloch off sign S1A, S1B | 79.8 | 14.4 |
| 48 Tied at sign B27, B28 | 9.2 | — |
| 49 Tied at sign B26, B27 | 1.7 | — |
| 50 Tied at sign B25, B26 | 21.8 | — |
| 51 Tied at sign B24, B25 | — | 6.0 |
| 53 Tied at sign B22, B23 | — | 4.0 |
| 54 Midloch off sign B22, B23 | — | 7.8 |
| 55 Midloch off sign B23, B24 | — | 4.0 |
| 57 Midloch off sign B25, B26 | 11.2 | — |
| 59 Midloch off sign B27, B28 | 39.8 | 38.3 |
| 60 Tied at B20 | — | 9.6 |
| 62 Center of slip B12, B16 | — | 3.6 |
| 63 Middle of entrance to slip B12, B16 | 16.1 | — |
| 64 Midloch off slip B7, B11 | — | 4.3 |
| 66 Tied at B10 | — | 5.5 |
| 67 Tied middle B9 | — | 12.7 |
| 69 Tied middle B7 | — | 2.5 |
| 70 Middle of entrance to slip B4, B6 | 11.3 | — |
| 71 Tied middle B4 | — | 3.8 |
| 74 Tied at north end of Ten Ten dock | — | 1.0 |
| 76 Tied at south end of Ten Ten dock | — | .8 |
| 77 Tied at midcaisson dry dock 1 | 24.6 | 2.6 |
| 78 Tied at midcaisson dry dock 2 | 2.4 | 3.2 |
| 79 Tied at midcaisson dry dock 3 | — | .6 |
| 80 Tied at Dolphins off finger piers at GD6 | — | .9 |
| 81 20 yards off landing C | 1.0 | — |
| 84 Tied at midcaisson dry dock 4 | .4 | — |
| 85 Tied Hickam Field wharf | .1 | — |
| 86 Tied Fort Weaver wharf | — | .1 |
| 87 Tied middle of W4 NAD | .1 | .1 |
| 88 50 yards off fish pond | ND | — |
| 89 Tied at W21 | — | .1 |
| 93 Midchannel between markers 39 and 40 | .9 | .8 |
| 95 Tied at D1–N | .4 | — |
| 96 Tied at D8–N | .2 | — |
| 97 50 yards off entrance to Waiawa Stream | ND | — |
| 98 20 yards off L pier | .1 | — |
| 99 Tied middle of pier at Peninsula Point | .9 | .2 |
| 100 Shore line at V–4 | — | .5 |
| 101 Tied middle of F–9 | 1.3 | .2 |
| 102 Tied Mauka pier F–8 | — | 1.8 |
| 103 Tied at middle of F–5 | — | 1.3 |
| 105 Tied at tip of F–1 | — | .7 |
| 106 Tied at X15–S | 1.1 | .6 |
| 65[b] 50 yards off finger piers, Pearl City Peninsula | — | .2 |
| 67[b] Tied at channel marker | — | .1 |
| 89[b] Midchannel off W–16 | — | .3 |

[a] Limit of detectability, 0.04 pCi/g dry weight.
[b] 1968 location number.
ND, nondetectable.

nated silt by 1968, thereby diluting the activity collected by the dredge samples.

Observation of the radionuclide deposition pattern within the harbor in 1966 and 1968 (figures 3 and 5) shows that the cobalt-60 has not undergone any noticeable migration or dispersion from southeast loch to previously uncontaminated areas.

*Some significant characteristics of the cobalt-60 in the sediments*

Because analysis of the field and laboratory data indicated a localization of the cobalt-60 activity in the sediment which correlated with deposition in the vicinity of the probable sites of isotope injection into the harbor, an investigation of the nature of cobalt-60 released from marine reactors was undertaken. The lack of dispersion of the cobalt-60 activity suggested the possibility that cobalt-60 was discharged in a physico-chemical form which facilitated rapid settling and binding in the sediment. Little information is available on the behavior of marine reactor effluent in the environment; however, cobalt-60 is a neutron-activated corrosion product, and the removal of stainless-steel

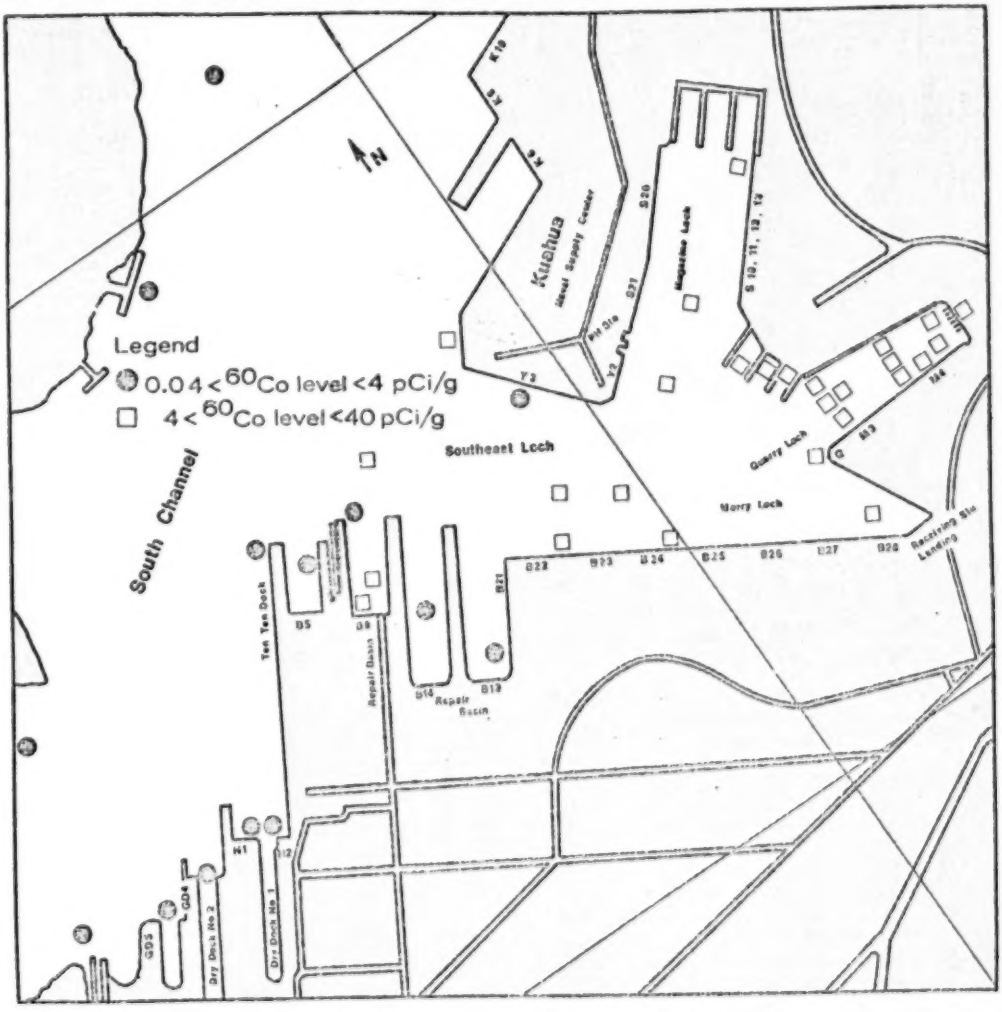


Figure 6. Relative 1968 cobalt-60 levels in Pearl Harbor (area of highest concentration)

Table 3. Core sample analysis, concentration of cobalt-60 in relation to depth (pCi/g dry weight)

| Depth below surface (inches) | Sample number | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1 | 1.5 | 4.4 | 4.7 | 1.2 | 25.9 | 2.0 | 0.6 | 2.5 | 1.5 | | | | | | | 0.3 | 0.1 |
| 2 | 10.3 | 10.3 | 13.4 | 1.1 | 22.7 | .9 | .6 | 3.9 | | | | | | | | | |
| 3 | 20.4 | 13.2 | 9.7 | 2.1 | 55.3 | 1.5 | 1.1 | 10.3 | | | | 0.2 | | | | | .1 |
| 4 | 13.2 | 7.9 | 8.6 | 1.5 | 35.8 | 2.4 | 10.4 | 8.0 | | | | | | 0.5 | | | |
| 5 | 13.7 | 15.4 | 24.5 | 1.4 | 16.7 | 35.2 | 3.9 | 3.9 | | | | | | | | | |
| 6 | 6.4 | 18.8 | 8.0 | 3.9 | 44.0 | 17.1 | 2.6 | 1.4 | | | | | | | | | |
| 7 | 45.1 | 35.2 | 19.0 | 9.9 | 90.1 | 2.7 | 1.4 | 5.4 | | | | | | | | | |
| 8 | 9.9 | 12.0 | 13.7 | 13.8 | 52.2 | 23.7 | 1.6 | 18.6 | | 7.8 | | .3 | 0.3 | | 0.3 | | |
| 9 | 9.1 | 11.2 | 11.8 | 14.4 | 22.4 | 1.2 | 3.3 | 7.8 | | | | | | | | | |
| 10 | 18.4 | 16.3 | 12.3 | 8.0 | 17.5 | 3.7 | 5.4 | 15.1 | | | | | | | | | |
| 11 | 27.1 | 21.1 | 40.1 | 28.0 | 32.3 | 12.7 | 13.5 | 2.5 | | | | | | | | | |
| 12 | 25.2 | 41.7 | 97.6 | 26.0 | 3.1 | 31.5 | 21.9 | .4 | | | 3.8 | | .5 | | .2 | | |
| 13 | 40.0 | 96.4 | 97.4 | 26.3 | 5.1 | 25.9 | 5.6 | .2 | | | | .2 | | | | | |
| 14 | 57.2 | 38.3 | .0 | 75.6 | .9 | 55.5 | 1.0 | .0 | | | | | | | | | |
| 15 | 65.4 | | .0 | 164.9 | .6 | 27.4 | .0 | .2 | | | | | | | | | |
| 16 | | | .0 | 248.0 | 2.1 | 131.5 | | .4 | | | | .2 | | | | | |
| 17 | | | .3 | 66.2 | 16.4 | 28.0 | | .0 | | | | | | | | | |
| 18 | | | .0 | 18.7 | | 12.2 | | .7 | | | | | | | | | |
| 19 | | | .0 | 28.4 | | .6 | | .4 | | | | | | | | | |
| 20 | | | .1 | .2 | | .0 | | .4 | | | | | | | | | |
| 21 | | | | .4 | | 18.2 | | 1.4 | | | | | | | | | |
| 22 | | | | 109.4 | | 24.1 | | | | | | | | | | | |

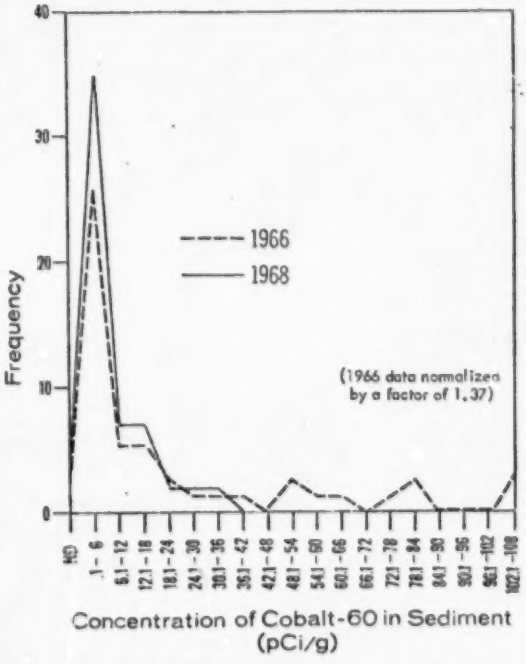


Figure 7. Frequency distribution of cobalt-60 data for 1966 and 1968

corrosion products by magnet from the ion exchange resin through which reactor primary coolant water passes prior to discharge has been reported (*5*). To investigate the chemical form of the nuclide, gamma pulse-height analysis of harbor sediment slurries was performed to determine their cobalt-60 activities. The solid and liquid phases were then separated by filtration and each phase scanned for its respective cobalt-60 activity. The filtrates contained no detectable cobalt-60 radioactivity.

The dried sediments were reconstituted to a slurry with demineralized water and stirred with a bar magnet. Metallic particles were readily separated by the magnet and found to contain cobalt-60 activity.

In order to determine how much of the resident activity in the sediment was present in association with these metallic particles, a container was constructed to hold a kilogram of dried sediment and sufficient demineralized water was added to produce a slurry. No further preparation of the silt was necessary. A revolving paddle wheel was used to keep the silt suspended. An electromagnet with a plastic cap was placed on the surface of the slurry to collect the magnetic particles. This geometry permitted the removal of the magnetic component of the slurry as free as possible of accompanying silt. Successive 15-minute separations throughout a 6-hour period were found to be the most efficient method of collection because the electromagnet's surface quickly became saturated with particles which hampered further extraction from the suspension.

The magnetic removal of cobalt-60 activity

resulted in greater than 90 percent decontamination of several of the sediment samples. A typical result of these experiments is shown in the gamma spectra of figure 8. The spectra show a decrease in the initial cobalt-60 activity of the sediment with successive magnet extractions and, within counting error, the corresponding activity loss was accounted for in the isolated particles.

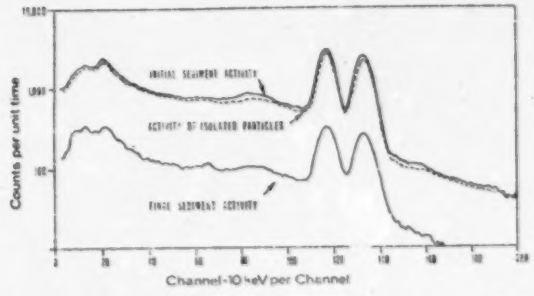


**Figure 8. Results of magnetic extraction of cobalt-60 from harbor sediment**

The collected particles were subjected to particle size analysis by passing a slurry of the particles through a U.S. Standard Sieve Series and Millipore filters. The results showed that approximately 90 percent of the cobalt-60 activity was associated with particles of 10–37 $\mu$m diameter. Attempts to remove the activity from the particles with dilute and concentrated reagents were unsuccessful, indicating that the cobalt-60 was an integral part of the particles.

Qualitative chemical analyses of aliquots of the isolated particles were performed by partial dissolution in aqua regia and subjecting the residue to an alkaline carbonate fusion. The solutions were combined and silicon oxide removed by repeated evaporation with concentrated HF. Paper chromatographic separations were performed with a solvent containing acetone, concentrated HCl and water (8:1:1 by volume) using Whatman No. 3 paper (*6*). Nickel, iron, and chromium could be readily identified. Cobalt apparently was present only in trace amounts. Trace concentrations of manganese were also inferred from the results of gamma coincidence-anticoincidence analysis of the particles which showed the presence of a 0.84 MeV peak, possibly manganese-54. Quantitative analyses were also performed on these solutions using the ion exchange separation procedure of Hague, et al. (*7*) and conventional precipitation techniques. The composition proved to be an iron alloy containing variable amounts of nickel and chromium.

Thus, it was demonstrated that the cobalt-60 activity found in the sediment of this harbor exists for the most part and possibly entirely in association with metal particles. The qualitative and quantitative analyses and the coincidence- anticoincidence counting of the particles suggest a stainless-steel composition. The size distrbution of the radioactive particles supports the idea that the cobalt-60 resulted from reactor corrosion products too small to be retained in the system and the resin bed and which had been discharged into the harbor with the water from reactor coolant expansion volume.

Preliminary studies were conducted to ascertain the magnitude of any assimilation of this metallic particulate form of cobalt-60 by bottom-feeding marine organisms. Two approaches were attempted: the first involved the maintenance of several varieties of bottom-feeding organisms in an environment containing fresh radioactive harbor sediment, and the second utilized isolated radioactive particles as an additive to fish food.

In a laboratory study, a circulating sea water aquarium was used to hold 2 liters of a slurry of Pearl Harbor sediment with a cobalt-60 activity of 48,800 pCi/liter or a total activity of approximately 0.1 $\mu$Ci. Clams, oysters, shrimp, and mullet were introduced into this environment after their background gamma activity had been determined by pulse-height analysis. This experiment was carried out for 2 months. The organisms were counted every second day for the first 2 weeks, and once each week for the remainder of the experiment. The counting procedure for clams and oysters entailed a thorough rinsing with distilled water to remove silt from the shells and counting for 30 minutes on a 200-channel gamma pulse-height analyzer. The fish and shrimp were first anesthetized in a solution of 75 and 300 ppm, respectively, of tricainemethanesulphonate, then placed in a tubular holder with an aeration outlet, and counted for 30 minutes.

In the second experiment, two seawater aquaria were divided into eight compartments and two mullet housed in each. The mullet were counted individually for background activity as previously described. The fish were then fed a blended diet composed of equal parts of baby beef liver, spinach, and pablum to which had been added cleansed particles, magnetically isolated from harbor sediment, containing cobalt-60 activity. The activity of the food thus prepared was determined to be 45 pCi/g by counting six 10-g aliquots. Each compartment was allowed 2 g/day for 6 days each week. The absence of feeding on the 7th day encouraged the fish to consume any residue remaining from previous feedings. The experiment was conducted for 21 days with 18 feedings, and counting was performed twice each week.

The organisms existing in the contaminated sediment environment (total cobalt-60 activity of 0.1 $\mu$Ci) exhibited no activity levels above the limit of detection of cobalt-60 which was 50 pCi under these conditions of counting geometry.

The fish which had been fed the cobalt-60 diet also showed no assimilation of a detectable body burden. However, because of the relatively low levels of activity utilized, amounting to a possible total intake of 810 pCi per fish, assuming each fish received the same amount of food, it can only be said that rapid and large scale uptake was not evident. A small level of assimilation could have occurred, but if so, it was below the limit of detection of cobalt-60.

### *Conclusions*

In view of these results which indicate that cobalt-60 from marine reactors is not concentrated in representative types of marine biota, this cobalt-60 does not appear to be an internal radiation hazard. Furthermore, calculations based on the assumption of a plane isotropic cobalt-60 source of infinite extent in the sediment reveal that the external radiation dose at the air-surface interface is too small to be calculable.

The radiological surveys of Pearl Harbor indicate that the total amount of cobalt-60 in the harbor sediment is small compared to the natural radioactivity and has decreased from 1966 to 1968. The levels of cobalt-60 activity are below levels that could contribute a detectable radiation exposure to the public and do not constitute a hazard to public health or the environment. Further, the chemical form of cobalt-60 released from marine reactors, and possibly reactors in general, is in the form of metallic corrosion product particles which do not appear to be assimilated or transmitted in the food chain.

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